

Model Reduction of Multibody Dynamics in Railways

Background and objective

Multibody models are essential for predicting the dynamic behavior of railway vehicles. These models consist of the car body, bogie frames, wheelsets, suspension components, and connecting elements as an assembly of rigid bodies linked through kinematic constraints, springs, dampers, and nonlinear force elements modelling contact between the wheels and rails.

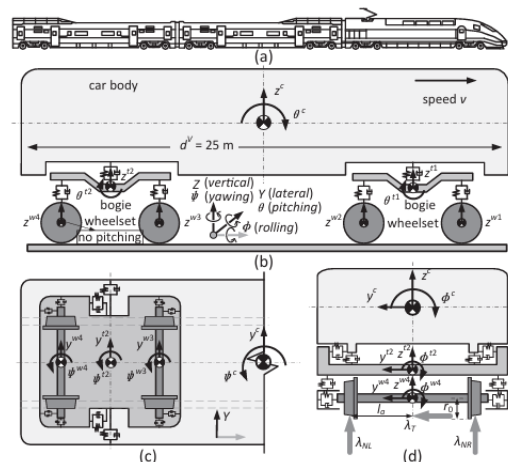


Figure: A train traversing a simply supported bridge (left) and a multi-DOF railway vehicle model (right)

Rigid-body vehicle models typically contain fewer degrees of freedom (DOF) than their flexible counterparts, yet their repeated simulation is computationally demanding, especially in the context of parameter studies, optimization, uncertainty quantification, real-time simulation, state estimation, control-system development, or repeated analyses of vehicle-track interaction. Model reduction techniques facilitate drastically lower computational costs by replacing the original multibody model with a lower-dimensional representation that reproduces the dynamic quantities of interest.

The objective of this project is to investigate, implement, and evaluate model reduction techniques for rigid multibody systems, with applications to a representative railway vehicle model. The resulting reduced-order model (ROM) should capture the dominant vehicle dynamics, preserve the influence of suspension and wheel-rail contact forces, remain valid over a relevant range of operating conditions, and provide physically meaningful outputs.

This project will be co-supervised by the following groups:

- Delft Institute of Applied Mathematics, TU Delft: contact Shobhit Jain Shobhit.Jain@tudelft.nl
- Chair of Structural Mechanics and Monitoring, ETH Zurich, contact Charikleia Stoura charikleia.stoura@ibk.baug.ethz.ch, Eleni Chatzi chatzi@ibk.baug.ethz.ch

Activities and Milestones

Literature review and preliminary research

- Fundamentals of rigid-body multibody dynamics with application to railway vehicles
- Review of model-order-reduction techniques for mechanical and multibody systems
- Identification of suitable reduction methods for railway vehicle models

Railway vehicle modeling

- Development of a prototypical rigid-body multibody railway vehicle model
- Definition of representative excitation cases, operating conditions, and response quantities
- Validating the developed model against available specialized external packages such as SIMPACK.

Model reduction and validation

- Implementation of selected model-order-reduction techniques
- Development of reduced-order railway vehicle models
- Validation of the reduced models against the full-order model in terms of accuracy, stability, and computational efficiency
- Assessment of the reduced models under different vehicle speeds, track irregularities, loading conditions, and suspension parameters

Deliverables: Interim presentation; thesis report; documented scripts, models, and simulation data; final presentation

Prerequisites

- Knowledge of calculus, linear algebra and numerical methods
- Affinity to programming in MATLAB or Python

Desirable: Background in dynamics, multibody systems, railway vehicle dynamics, model reduction, experience with using SIMPACK.

Sample literature

1. Shabana, A.A. (2020) *Dynamics of Multibody Systems*, 5th ed., Cambridge University Press.
2. Shabana, A.A., Zaazaa, K.E., & Sugiyama, H. (2007) *Railroad Vehicle Dynamics: A Computational Approach*, CRC Press.
3. Wu, L., Tiso, P. (2016) Nonlinear model order reduction for flexible multibody dynamics: a modal derivatives approach. *Multibody Syst Dyn* **36**, 405–425
4. Lehner, M. & Eberhard, P. (2006) On the use of moment-matching to build reduced order models in flexible multibody dynamics. *Multibody System Dynamics*, 16(2), 191–211.
5. Fehr, J. & Eberhard, P. (2011) Simulation process of flexible multibody systems with non-modal model order reduction techniques. *Multibody System Dynamics*, 25(3), 313–334.
6. Angeli, A., Naets, F., & Desmet, W. (2021) Deep learning for model order reduction of multibody systems to minimal coordinates. *Computer Methods in Applied Mechanics and Engineering*, 373, 113517.
7. Li, M., Jain, S. & Haller, G. Model reduction for constrained mechanical systems via spectral submanifolds. *Nonlinear Dyn* 111, 8881–8911 (2023).